



## AMS : a cosmic ray observatory

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## **AMS : a cosmic ray observatory**

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**AMS : A Cosmic Ray Observatory**  
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**For the AMS collaboration**

## Abstract

The Alpha Magnetic Spectrometer (AMS) is a particle physics detector designed to operate in space beyond the earth atmosphere. AMS will measure all the charged cosmic rays and light nuclei spectra in the GV to TV rigidity domain, and high energy cosmic gamma rays as well. With a large acceptance, at least 3 years of observation, and state of the art redundant particle identification techniques, AMS will provide a continuous survey of charged cosmic rays fluxes and the most sensitive search for the existence of anti matter nuclei and for the origin of dark matter. The detector construction will be completed by 2005. AMS should be installed on the ISS (International Space Station) in 2007 and will record several billions cosmic rays per year of operation.

## Introduction

Though the deep sky was observed for decades by balloon-borne and space experiments, and by instruments on the earth as well, most of the mass of the universe is still of unknown nature. The matter-antimatter asymmetry of the universe is still controversial, since no experiment was sensitive enough to detect primordial antimatter, and no theory was able to find a natural mechanism of baryogenesis compatible with the current knowledge in particle physics. More than 80 per cent of the mass of the universe could be made of non-baryonic dark matter, but the best candidate, the lightest super-symmetric particle neutralino, has not been observed in any experiment so far.

To reach the high sensitivity necessary for studying such key issues, AMS02 was designed as a large acceptance magnetic spectrometer to be operated on the international space station for at least 3 years, in order to get rid of backgrounds and absorption due to the earth atmosphere, and to record a very large statistics. The misidentification probability which must be as low as  $10^{-10}$  for antihelium versus helium separation is reached through many independent measurements of each cosmic particle traversing the AMS detector.

## The AMS01 precursor flight

A magnetic spectrometer which is a typical detector in high energy physics had never been flown in space. In order to test the technology and to have a first measurement of the environmental conditions on the space station, a first magnetic spectrometer was flown on board of the space shuttle Discovery.

This so called AMS01 precursor flight took place in june 1998 and lasted 10 days.

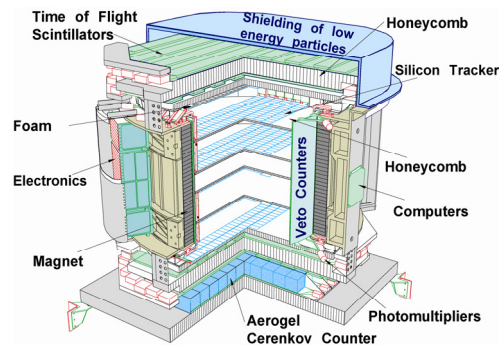


Fig. 1 The AMS01 detector.

The AMS01 consisted mainly of a permanent magnet with a pending power of  $0.14 \text{ Tm}^2$ , a silicon tracker, anticoincidence counters, 4 time of flight hodoscopes, and an aerogel threshold Cerenkov counter. The acceptance was about  $0.3 \text{ m}^2\text{Sr}$ .



Fig 2. AMS01 in the rear of the cargo bay of Discovery seen from MIR

Though it was only an engineering flight, more than 100 millions events were collected. In addition to validating the AMS concept, analysis of these

events led to significant results [1-7], among with the measurement of fluxes of protons, electrons, and helium above and below the geomagnetic threshold, and the unexpected observation of trapped and quasi-trapped high energy cosmic rays near the equator. These results have been used for accurate prediction of atmospheric neutrinos for other experiments [8].

The AMS02 detector [9]

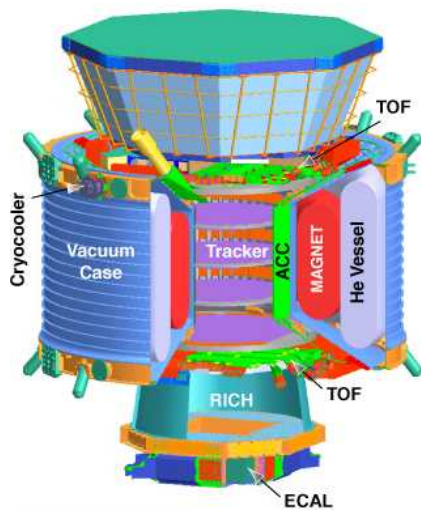


Fig. 3 The AMS02 detector. It is roughly 3m.3m.3m in volume and weights 7 tons.

The core of the instrument is an eight planes silicon tracker inside a cylindrical superconducting magnet (fig. 3) with an acceptance of  $0.6 \text{ m}^2\text{Sr}$ .

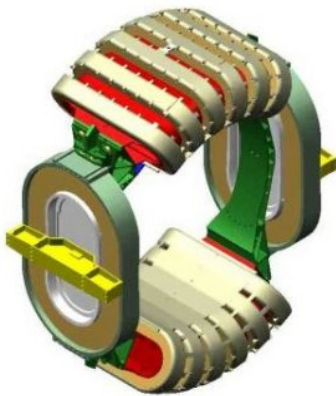


Fig 4. The magnet coil system. Outside the magnet, the flux from the 2 dipole coils is compensated by the return flux generated by the 12 racetrack coils.

The magnet comprises 2 dipoles coils and 12 racetrack coils designed to produce a dipole field with a bending power of  $0.8 \text{ Tm}^2$  inside a volume of 1.15 meter in diameter and 1m height, while having no dipole momentum to avoid torque in the earth magnetic field. The coils are built with a special aluminum stabilized NbTi/copper composite conductor which allows to reduce the quench probability by a factor 2000. Cooling is made by superfluid helium with extraction of the heat by evaporation and by active cryocoolers. An helium tank of 3000 liters allows for 3 years of operations. The 14 coils have been built and tested successfully at the nominal current and no quench were observed.

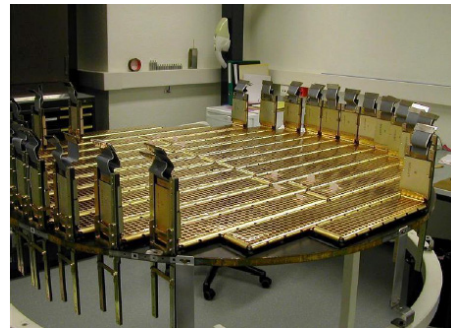


Fig 5. Construction of a plane of the silicon tracker.

The tracker (TRK) is made of eight layers of double-sided, high resistivity silicon strip detector of  $6.45 \text{ m}^2$  of total surface which provide a coordinate resolution of  $10 \mu\text{m}$  in the bending plane and  $30 \mu\text{m}$  in the non-bending plane, allowing a resolution  $dp/p$  better than 2% up to a rigidity of 10 GV/c and 20% at 1 TV/c .

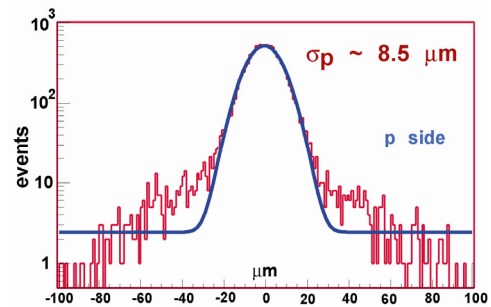


Fig. 6 Measurement of tracker accuracy in a 120 GeV/c muon test beam. A precision of reconstruction of  $8.5 \mu\text{m}$  was found.

The  $Z^2$  dependence of the energy deposition in the silicon by particles allow to identify nuclei up to Fe, as it was demonstrated in a test with an ion beam at CERN (fig. 7). Between the innermost face of the magnet and the cylindrical support structure of the tracker a layer of scintillating counters, the so-called anti-coincidence counters, acts as a veto to ensure that only particles passing through the magnet aperture are accepted and interaction in the bulk material are rejected.

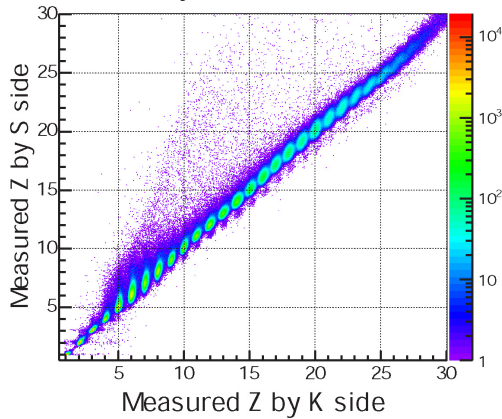


Fig.7 Comparison of signals in n and p sides of a silicon pad exposed to a beam of ions of many type.

A four layer time of flight hodoscope (TOF, talk by C.Sbarra, this conf.) placed above and below the tracker allows to measure the time of flight with an accuracy of 120ps and the direction of particles traversing the detector (to reject upward going particles from albedo). Each layer is made of a double plane of 11cm wide paddles of scintillator oriented respectively in X and Y, and read at both ends by a pair of photomultipliers. The TOF covers the full acceptance of the tracker and provides an additional measurement of velocity (for  $p < 1.5$  GeV/c) and  $Z^2$ . It is used for the charged primary fast trigger which requires hits in 3 planes of the TOF out of 4, and no signal in the veto counters.

A Ring Imaging Cerenkov Counter (RICH) measuring the velocity  $\beta$  of particles and nuclei to 0.1 percent accuracy and again  $Z^2$  together with momentum measurement in the tracker allow to measure directly the mass of cosmic rays up to  $A=25$  for momentum below 12 GeV/c/N, and to identify nuclei up to Fe for momentum up to 1 TeV/c/N. The dual solid radiator is made of 3 cm thick aerogel (optical index  $n=1.035$ , threshold 3 GeV/c)

with a central part made of NaF ( $n=1.14$ , threshold 1 GeV/c) to extend the energy range.

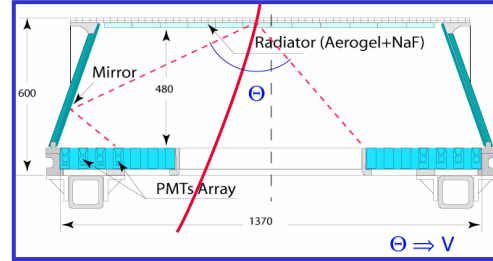


Fig 8. Schematic of the RICH detector

680 16-anodes PMT's are used to read the cerenkov light produced of which the collection is improved by a high quality conical mirror. Tests in beam at CERN together with tracker elements have shown that the expected performances are reached (Fig. 9).

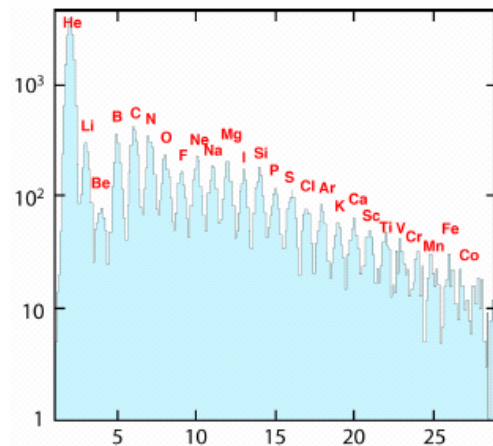


Fig. 9 Charge measurement with the RICH exposed to an ion beam.

The identification of electromagnetic particles is based on a transition radiation detector (TRD) on the top of the detector and an electromagnetic calorimeter (ECAL) placed underneath the RICH. The TRD is made of 20 planes built from a total of 328 modules, each consisting of 22mm fleece and 16 6mm diameter straw tubes filled with a gas mixture of 80% Xe and 20% CO<sub>2</sub> (Talk by T. Sindenburt, this conf.). It provides an electron/proton rejection factor between  $10^2$  and  $10^3$  in the energy range 1.5GeV-300GeV.



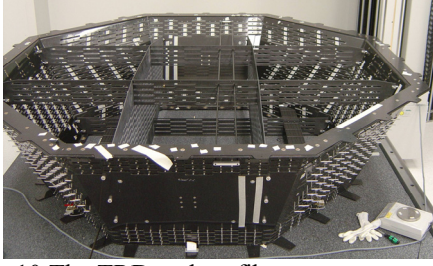


Fig. 10 The TRD carbon fiber support structure

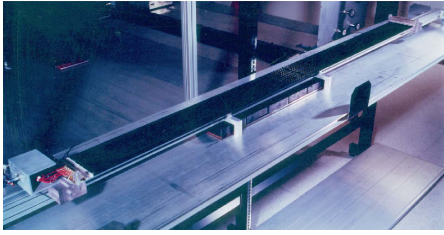


Fig. 11 A TRD module on assembly jig.

Combined with the ECAL, it allows an overall rejection electron/hadron better than  $10^6$ .

The 3D imaging electromagnetic calorimeter (ECAL) has an active area of  $648 \times 648$  mm<sup>2</sup> and consists 9 modules made of a sandwich of 11 mm thick grooved lead foils and of 10 layers of 1mm diameter scintillating fibers glued together with epoxy. The 9 modules are piled up with their fibers direction alternately in X and Y to provide full 3D sampling of the showers.

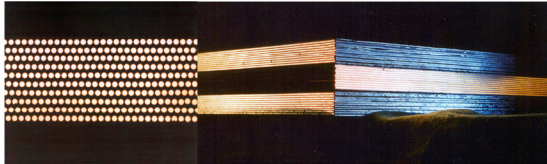


Fig. 12 Fibers in a superlayer (left) and 3 superlayers piled up with crossed x and y fibers direction (right)

The fibers are read alternatively at one end and the other by 324 4-anodes square PMT's with a pixel size of  $9 \times 9$  mm<sup>2</sup>. Since the radiation length is about 1cm, each pixel reads about  $0.9 X_0$  in depth and  $0.5$  Moliere radius transversally. This way a very high granularity is obtained without any dead space. The total depth is about  $16.7 X_0$ . For each PM, the signals from the 4 pixels and from the last dynode is readout by an ASIC which cover the dynamic range of 60,000 from the signal of a the minimum ionizing particle to the maximum energy deposition

in a cell by a 1 TeV electromagnetic shower. In superlayers 2 to 7, the signals of the last dynode of PMT's is used to form a fast trigger for cosmic gamma rays above 1 GeV converting directly in the ECAL.

Exposed to a beam of electrons and protons at CERN, the ECAL performances were found to be

$$\frac{\delta E}{E} = \frac{(10.2 \pm 0.3)\%}{\sqrt{E(\text{GeV})}} \oplus (2.3 \pm 0.1)\% \text{ for the energy}$$

resolution, and, for the angular resolution

$$\Delta\theta_{68\%} = \frac{(8.6 \pm 0.1)}{\sqrt{E(\text{GeV})}} \oplus (0.57 \pm 0.04)\% \text{ (in degrees).}$$

Comparing electrons of 50 GeV with 120 GeV protons (energy at which protons have the highest probability of being misidentified as 50 GeV electrons) it was found a rejection factor of about 250 with a 95% efficiency for the electrons without using E/p matching.

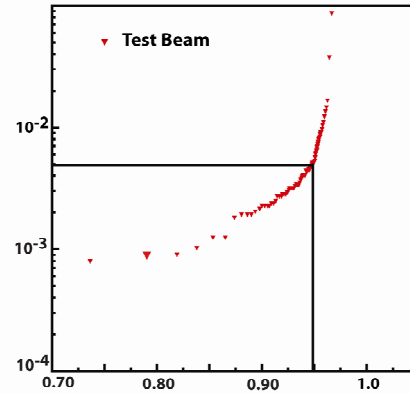


Fig. 13 rejection power of 120GeV/c protons as a function of electron efficiency for 50 GeV electrons

The AMS02 detector also comprises a star tracker system in order to take profit of the 2 arc minutes angular resolution of the tracker for localizing the sources of high energy gamma rays. Eventually, a GPS system allows to record the time of each event with an accuracy of a few microseconds and will make possible the correlation of the events observed in AMS with the observation of other experiments.

All the detectors have been submitted successfully to very demanding tests of acceleration (up to 17g), vibration (6.8g rms), vacuum and thermal cycles (from  $-40^{\circ}\text{C}$  to  $+50^{\circ}\text{C}$ ) to check that they are qualified for space operations.

Apart from front-end electronics boards on the subdetectors, all the electronics was designed to be redundant (each digital board has a hot and cold part) to ensure a high reliability even in the very constraining space environment. The level of redundancy is as high as 6 for the most critical DAQ boards. The DAQ system will reduce the 7 GBit/s raw data rate to an average of 2Mbit/s which will be sent to the ground segment via the high rate data link of the space station in the Ku band. A low rate data link will allow to send commands to the detector from the Payload operation control center which will be installed at CERN.

A computer system, the so-called AMS Crew Operation Post (ACOP), connected to the AMS detector through the fiber optic of the high rate data link will be located in the US lab onboard the ISS. Its main function will be to archive the data on removable hard drive as a backup to avoid any loss of data. The hard drive will be replaced when data are recorded and transported to the ground as a permanent archive. The ACOP will allow the crew onboard the ISS to monitor and if necessary to command the experiment.

#### Physics with AMS02

AMS02 was designed to measure with high precision and high statistics the fluxes of charged particles and light nuclei with their isotopic content, with an increase of 3 to 4 order of magnitude compared with the existing experiment.

The tests made on the engineering models of each subdetector of AMS02 as described above show that they reach the design performances. The addition of the gamma trigger of the ECAL and of the star tracker and GPS will also open to AMS02 the domain of high energy gamma rays. A key point of the measurements with AMS02 is that all the fluxes are measured simultaneously and in the same condition, allowing to correlate measurement, which will give strong constraints on the models of cosmic rays. In case a signal is observed, it will also allow to compare different channel and thus improve the sensitivity of the experiment.

Some examples of measurements expected with AMS02 are given below.

For the search for primordial antimatter, AMS02 should be able to lower the limit on the ratio antihelium/helium to  $10^{-9}$ , which is 3 order of magnitude lower than the current limit.

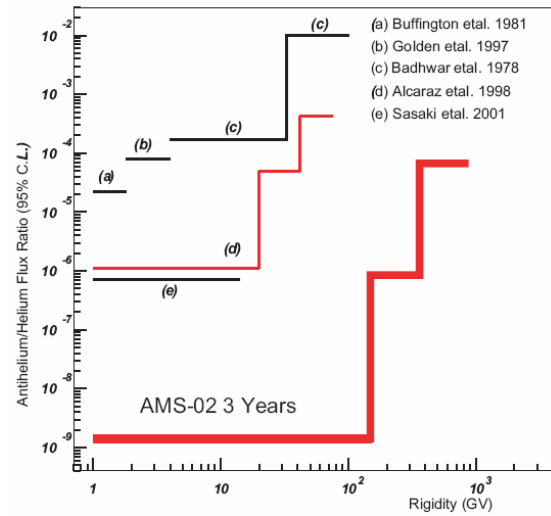


Fig. 14 Projected AMS02 limit on the  $\overline{\text{He}}/\text{He}$  ratio compared to previous measurements.

For the search of dark matter, a signal from neutralino annihilation could be observed in positron, gamma, and antiproton spectra.

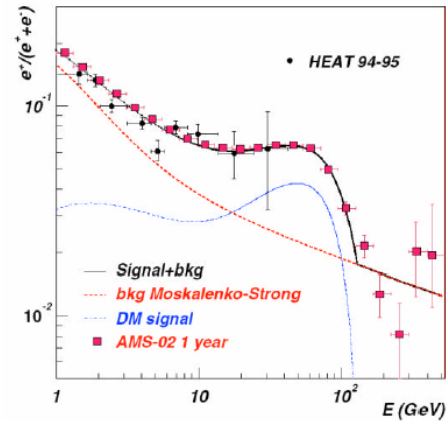


Fig. 15 Example of positron spectrum with/without dark matter and AMS02 sensitivity.

The figure above gives the example of positron spectra obtained in 1 year with AMS.

Some ratio of fluxes of nuclei are very important for the understanding of the dynamics of galaxy and for the measurement of confinement. The figures below show the example for the B/C ratio and for the  $^{10}\text{Be}/^9\text{Be}$  ratio. In the case of Beryllium, most of the energy spectrum has no experimental data yet. Gamma ray fluxes and sources in the range 10GeV-300 GeV are almost unexplored today.

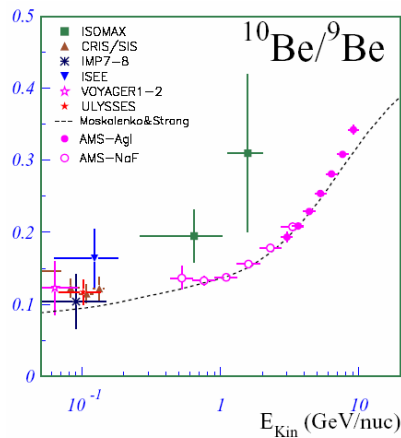


Fig. 16 projected AMS 1 year measurement of the  $^{10}\text{Be}/^9\text{Be}$  ratio energy dependence

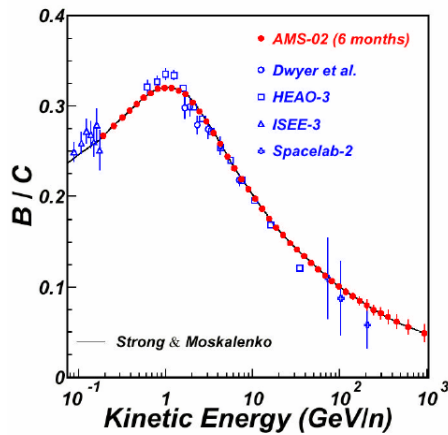


Fig. 17 projected 6 month of data taking with AMS for the B/C ratio energy dependence.

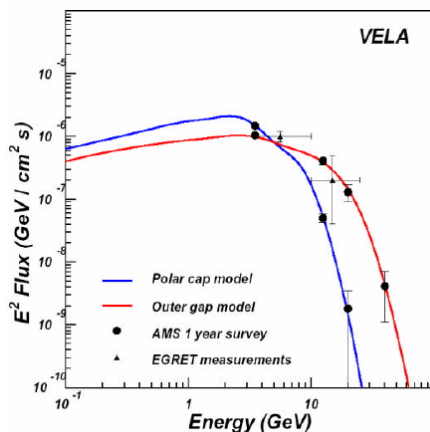


Fig. 18 Vela pulsar example of 1 year of AMS

As an example, the fig. 18 above shows that in 1 year of survey AMS02 will be able to decide between polar cap and outer gap models

## Conclusion

The design, prototype, and qualification phase of the AMS02 detector has been successfully completed. Most of the flight hardware will be built by the end of 2004. A final thermal vacuum test of the full detector should take place in ESA/Noordwijk by the end of 2005. The detector is expected to be installed for 3 to 5 years as from 2007 on the International Space Station.

## Acknowledgements.

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